TECTONO-METAMORPHIC HISTORY OF THE DUARTE TERRANE (JARABACOA AREA, HISPANIOLA ISLAND): INSIGHTS ON THE TECTONIC EVOLUTION OF THE NORTHERN RIM OF THE CARIBBEAN OCEANIC PLATEAU

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ABSTRACT

The northern margin of the Caribbean Plate is characterized by a transpressional belt consisting of an assemblage of several terranes derived from Late Cretaceous to Tertiary oblique convergence between the Northern American and Caribbean Plates. Fragments of the oceanic plateau belonging to the Caribbean Plate are incorporated in these belts as strongly deformed and metamorphosed sequences, as recognized in the Jarabacoa area of the Hispaniola Island. In this area the Duarte Terrane consists of two different units showing different metamorphic grades. The lower unit consists of greenschist facies metabasites, whereas the upper one is represented by amphibolite facies metabasites topped by metasedimentary rocks, whose protoliths were clastic deposits supplied by a magmatic arc. Both units suffered four deformation phases, from D_1 to D_4, that can be strictly correlated. In both units the D_1 phase is characterized by a syn-metamorphic foliation associated to a mineral lineation and very rare rootless isoclinal folds. The D_2 phase is characterized by a well developed foliation and isoclinal folds acquired under retrograde metamorphic conditions. The D_1 and D_2 phases developed in the Cenomanian-Turonian time span. The following D_3 and D_4 phases produced weak deformations without metamorphic imprint. The D_3 and D_4 phase are probably connected with transpression tectonics of Early Oligocene to Early Miocene age. All these deformations developed in an arc setting connected with southward oblique subduction of the oceanic lithosphere of the North America Plate beneath the Caribbean oceanic plateau.

INTRODUCTION

The Caribbean Plate has a composite structure that includes a small continental block showing a transition to a large igneous province represented by an oceanic plateau that covers a wide area of about 6x10^5 km^2 (e.g., Revillon et al., 2000). The crust of the plateau shows a thickness up to 20 km that is regarded as the result of Lower to Upper Cretaceous plume activity originally located in the Pacific (Duncan and Hargraves, 1984; Pindell et al., 1988; Pindell and Barrett, 1990; Kerr and Tarney, 2005) or in the Caribbean area (Meschede, 1998; Meschede and Frisch, 1998; Giunta et al., 2002; James, 2006). The northern border of the Caribbean Plate is represented by transpressional deformed belts, consisting of an assemblage of several terranes derived from Upper Cretaceous to Tertiary oblique convergence between the Northern America and the Caribbean Plates (Donnelly et al., 1990; Lewis and Draper, 1990; Draper et al., 1994; Mann, 1999; Giunta et al., 2003; Pindell et al., 2006; Escuder Viruete et al., 2006 and many others). Fragments of the oceanic plateau are incorporated in these deformed belts, as recognized in the Hispaniola Island located at the northern margin. In this island, the oceanic plateau is exposed as unmetamorphosed and weakly deformed sequences in the La Hotte-Selle-Borohuco Terrane, but also as strongly deformed and metamorphosed sequences in the Duarte Terrane. The latter one represents a good example of the oceanic plateau involved in the transpressional belt at the border of the Caribbean Plate.

In this paper the lithostratigraphic features, the deformation history and the metamorphic characteristics of the metabasites from the Duarte Terrane cropping out in the Jarabacoa area are described and the related implications for the geodynamic history of the northern border of the Caribbean Plate are discussed.

GEOLOGICAL FRAMEWORK OF HISPANIOLA ISLAND

The Caribbean Plate is located between the South and North America Plates (Fig. 1). Its northern and southern margins are both characterized by up to 300 km wide transpressional belts whereas the eastern and western margins consist of active subduction systems where the oceanic lithosphere, belonging to the Atlantic Ocean in the east and to the Pacific Ocean in the west, is subducted under the Caribbean Plate. The core the Caribbean Plate is mainly represented by undeformed and very thick oceanic and/or transitional lithosphere formed since Late Jurassic during the spreading between North and South America (Mauffret and Leroy, 1997; Sinton et al., 1998; Révillon et al., 2000; Escuder Viruete et al., 2007a). The deformed transpressional belts located at the northern and southern margins derived from a long-lived geodynamic history that includes the Jurassic-Lower Cretaceous development of the proto-Caribbean oceanic basin after the breakup of Pangea and the subsequent Eo-Caribbean oblique convergence of “mid” Cretaceous-Early Tertiary age resulting in a complex sequence of subduction, accretion, transpression, transtension

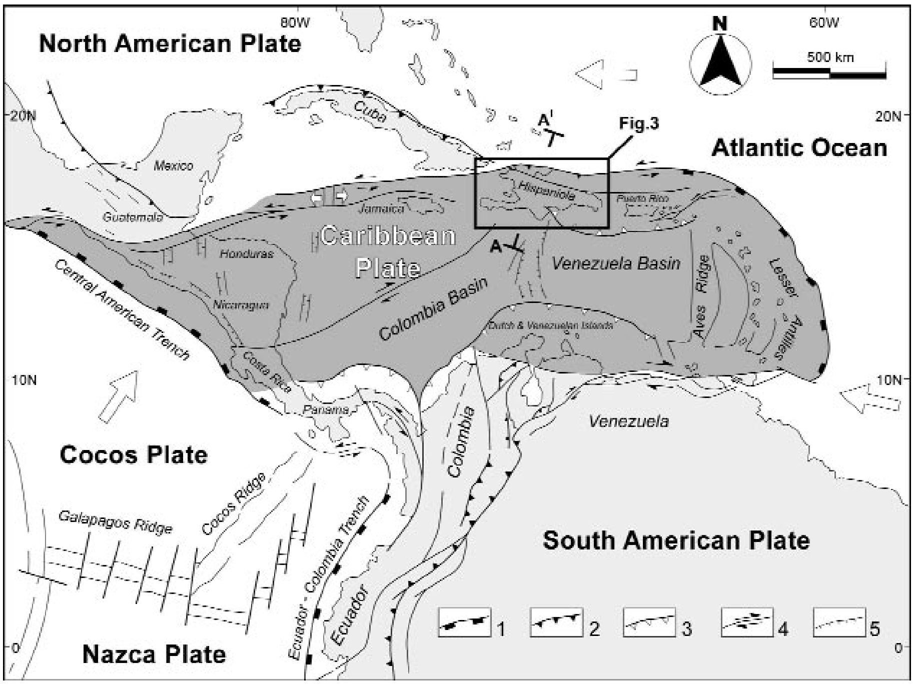

Fig 1 - Tectonic sketch of the Caribbean Plate. Arrows indicate the prevalent directions of plate movements. Main active tectonic features: (1) trenches and subduction zones; (2) frontal thrusts; (3) Tertiary accretionary prism; (4) strike-slip faults; (5) extensional faults (redrawn from Giunta et al., 2003). The location of the cross-section in Fig. 2 (AA') and the sketch map in Fig. 3 are also indicated.

and exhumation events (e.g. Dengo, 1985; Burke, 1988; Pindell et al., 1988; Pindell and Barrett, 1990; Meschede and Frisch, 1998; Kerr et al., 1999; Giunta et al., 2003; Beccaluva et al., 2004; 2006; Pindell et al., 2005). Most of the geodynamic models (e.g. Giunta et al., 2006) suggest that the angle between subduction zone and continental margin of the North America Plate caused a progressive eastward shifting in time and space of the continental collision along the northern margin of the Caribbean Plate. In this frame, the Hispaniola Island represents the central-eastern segment of the northern margin of the Caribbean Plate, where the deformed transpressional belt is interpreted as a fossil suture zone developed since the Late Cretaceous as result of oblique convergence between the Caribbean and the North American Plates (Fig. 2). According to Mann et al. (1991) the present-day tectonic setting of the Hispaniola Island consists of twelve amalgamated tectonostratigraphic terranes (*sensu* Coney, 1989), each bounded by WNW-ESE directed left lateral strike-slip faults associated to synthetic and antithetic NW-SE and NE-SW fault systems (Fig. 3). Three main domains can be identified: the Southern, Central and Northern Cordillera ones, each corresponding to a main morphotectonic element of the Hispaniola Island.

In the Southern Cordillera only the La Hotte-Selle-Borohuco Terrane crops out. This terrane, that is bounded northwards by the Enriquillo-Plantain Garden fault zone, consists of an uplifted portion of the Caribbean oceanic plateau made up of a thick, unmetamorphosed and weakly deformed sequence of Lower to Upper Cretaceous basalts, cherts and volcaniclastic deposits, covered by carbonate deposists of Paleocene-Miocene age (Sen et al., 1988; Vila et al., 1990).

The Central Cordillera is characterized by an assemblage of eight terranes, bounded northwards by the Septentrional fault zone. These eight terranes mainly include magmatic and sedimentary rocks derived from island-arc and oceanic plateau settings. The island-arc related rocks are preserved in the Tortue-Amina-Maimon-Los Ranchos, Tireo, Seibo, Oro and Presqu'ile du Nord-Ouest-Neibas Terranes, that mainly consists of basalts, dacites, rhyolites and andesites ranging in age from Early to Late Cretaceous. The island-arc sequences include also sedimentary rocks as cherts, volcanoclastic arenites and carbonates. The Trois Rivières-Peralta Terrane consists of a thick succession of deformed turbidites ranging in age from Late Cretaceous to Miocene, that have been interpreted as backarc deposits evolving to foredeep ones. The oceanic plateau derived rocks occur in the Loma Caribe-Tavera and Duarte Terranes (Lapierre et al., 1997; Escuder Viruete et al., 2007b). In the Duarte Terrane, basic volcanites consisting of high-Ti picrites associated to low-Ti, high-Mg and Fe-Ti basalts of probably Early Cretaceous age (> 96 Ma; Escuder Viruete et al., 2007b) are preserved. The Loma Caribe-Tavera Terrane consists of a less than 3 km thick

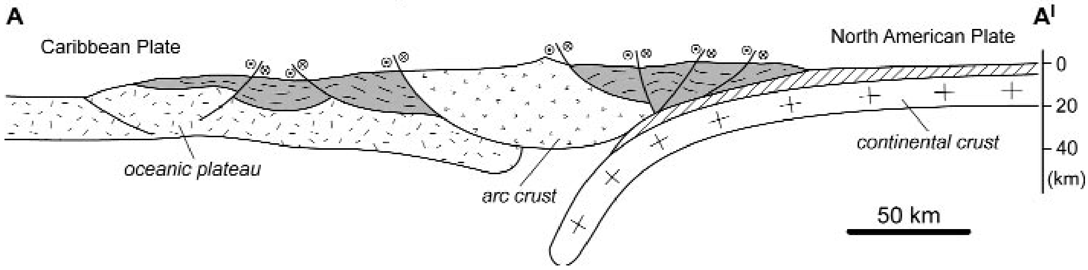

Fig 2 - Interpretative cross-section of the Caribbean-North American Plates margin in correspondance of the Hispaniola Island. The location of the cross-section is indicated in Fig. 1 (AA').

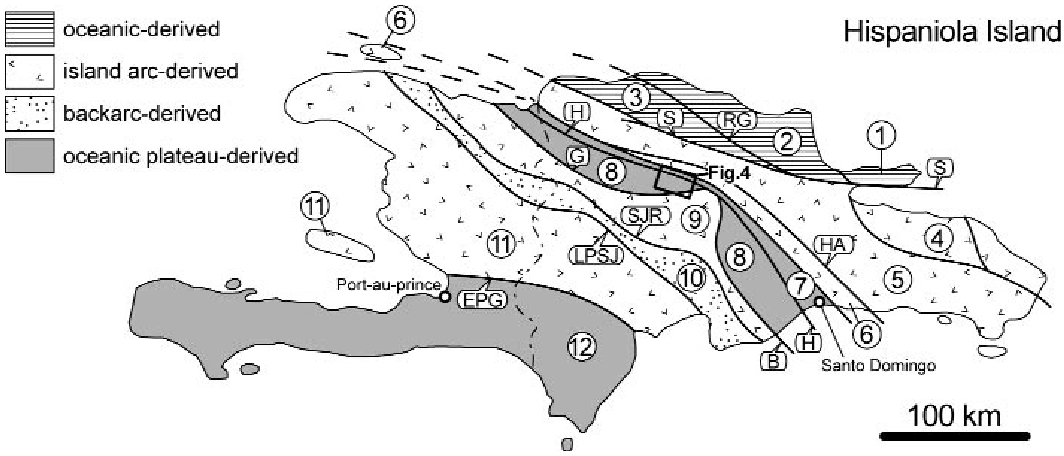

Fig 3 - Tectonic sketch map of the Hispaniola Island. (1) Samanà Terrane; (2) Puerto Plata-Pedro Garcia-Rio San Juan Terrane; (3) Altamira Terrane; (4) Oro Terrane; (5) Seibo Terrane; (6) Tortue-Amina-Maimon-Los Ranchos Terrane; (7) Loma Caribe-Tavera Terrane; (8) Duarte Terrane; (9) Tireo Terrane; (10) Trois Rivieres-Peralts Terrane; (11) Presqu'ile du Nord-Ouest-Neibas Terrane; (12) Hotte-Selle-Bahoruco Terrane; (RG) Rio Grande fault zone; (S) Septentrional fault zone; (G) Guacara fault zone; (HA) Hatillo fault zone; (H) Hispaniola fault zone; (B) Bonao fault zone; (SJR) San José Restauracion fault zone; (LPSJ) Los Pozos-San Juan fault zone; (EPG) Enriquillo-Plantain Garden fault zone. The location of Fig. 4 is indicated.

ophiolite sequence, including serpentinized peridotites, layered and isotropic gabbros with dolerite dykes and massive to pillowed basalts. The sedimentary cover consists of shales alternating with cherts, where a radiolarian assemblage of Oxfordian to Tithonian age has been found by Montgomery et al. (1994). This sequence is commonly interpreted as a remnant of the Upper Jurassic proto-Caribbean oceanic lithosphere (Lapierre et al., 1997; Escuder Viruete et al., 2007b). The terranes from the Central Cordillera were strongly deformed under low-grade metamorphism, with the exception of the Tortue-Amina-Maimon-Los Ranchos and Duarte Terranes, where greenschist to amphibolite facies metamorphic rocks occur (Draper and Lewis, 1991).

In the Northern Cordillera, an assemblage of three ocean-derived terranes occurs, two of them called Samanà and Puerto Plata-Pedro Garcia-Rio San Juan Terranes, are characterized by metaophiolites strongly deformed under high-pressure metamorphism, up to eclogite facies (Zack et al., 2004). Sm-Nd isochron ages (Grt-Omp-whole rock; Escuder Viruete and Perez-Estaun, 2006) suggest that the eclogite facies metamorphism ranges in age from Late Cretaceous to Early Eocene. These metaophiolites are interpreted as exhumed remnants of the deep levels of the accretionary wedge formed by the WSW/W-directed subduction of oceanic lithosphere beneath the Caribbean Plate. Their protolith is represented by MOR ophiolite sequences, probably of Late Jurassic age as found in other areas of the northern Caribbean margin (e.g. Chiari et al., 2007). The third one, the Altamira Terrane includes only unmetamorphosed sedimentary deposits of Paleocene to Eocene age.

Most of the terranes from the Central and Northern Cordillera were intruded by Upper Cretaceous calc-alkaline intrusive complexes, like those of Loma Cabrera or Jumunuco (e.g. Escuder Viruete et al., 2006), that were syntectonically emplaced during the Late Cretaceous.

The geophysical data (Mann et al. 2002, and quoted references) suggest that the terrane from Southern Cordillera, i.e. the La Hotte-Selle-Borohuco Terrane, belongs to the Caribbean oceanic plateau. By contrast, the terranes from Central and Northern Cordillera represent a collision belt bounded by crustal high-angle strike-slip fault zones that accommodated the oblique subduction of the North America Plate beneath the Caribbean one.

In the Hispaniola Terranes, the tectonic history of the Caribbean Plate, from the Jurassic-Cretaceous proto-Caribbean oceanic spreading to Upper Cretaceous eo-Caribbean convergence stages and the following collisional stages, can be fully reconstructed (Giunta et al., 2003; 2006, and quoted references). The development of the proto-Caribbean oceanic lithosphere in the Late Jurassic-Early Cretaceous time span is well recorded in the Loma Caribe-Tavera Terrane from the Southern Cordillera. This oceanic lithosphere was progressively thickened as a result of the Lower Cretaceous mantle plume related magmatism well recorded in both the La Hotte-Selle-Bohoruco Terrane in the Southern Cordillera, and the Duarte Terrane in the Central Cordillera. The inception of subduction between the Caribbean and North America Plates was recorded by arc-related magmatism in the Early to Late Cretaceous, as recognized for instance in the Tortue-Amina-Maimon-Los Ranchos, Tireo, Seibo, Oro and Presqu'ile du Nord-Ouest-Neibas Terranes. Two different arc-related stages of magmatism have been recognized by Lewis et al. (2002). The first one occurred in the Early Cretaceous as a consequence of the northward intraoceanic subduction developed inside the proto-Caribbean oceanic domain. This subduction resulted in collision of the oceanic plateau with the first stage arc system. According to the model proposed by Lewis et al. (2002), the second stage of arc-related magmatism occurred since Aptian times as a result of a reversal in subduction polarity. During this stage the southward oblique subduction of the oceanic lithosphere of the North America Plate beneath the Caribbean oceanic plateau resulted in the development of a trench-accretionary wedge-arc system, subsequently deformed during the collision. The subduction events are recorded by the high-pressure metaophiolites from the Samanà and Puerto Plata-Pedro Garcia-Rio San Juan Terranes in the Northern Cordillera. By contrast, evidence of the collision stage is provided by deformations detected in the Central Cordillera, as those recognized in the Duarte Terrane. The tectonic structures connected to this history are sealed by Upper Eocene to Pliocene sedimentary rocks. The post-Upper Eocene tectonics is dominated by strike-slip tectonics related to oblique subduction between the Caribbean and North America Plates, still active today in the Puerto Rico trench.

GEOLOGICAL SETTING OF JARABACOA AREA

The studied area is located in the north-eastern border of the Central Cordillera in the La Vega and Santiago provinces, between the Jarabacoa, Janico and La Vega villages (Fig. 4). The main river that crosses the Jarabacoa area is Rio Yaque of Norte. In this area, the bulk of the Central Cordillera consists of three WNW-ESE trending terranes, each bounded by left lateral WNW-ESE and NW-SE trending strike-slip faults. From south to north they are: Tireo, Duarte and Loma Caribe-Tavera Terranes. The Tireo and Duarte Terranes are separated by the Bonao fault zone, whereas the Duarte and Loma Caribe-Tavera ones are separated by faults belonging to the Hispaniola fault zone.

The Tireo Terrane (not cropping out in the area of the geological sketch map of Fig. 4) includes Upper Cretaceous (Coniacian-Maastrichtian) volcanoclastic rocks interfingering with basalts, andesites and rhyolites. These volcanic rocks are regarded as related to the second arc stage (Lewis et al., 2002; Escuder Viruete et al., 2006) even if its basal portions can be associated to a late volcanic evolution of the oceanic plateau (Lewis et al., 2002; Beccaluva et al., 2004). According to Lewis et al. (2002), these volcanic rocks are generally detached from a basement similar to that recognized in the Duarte Terrane, i.e. a basement belonging to the the Caribbean oceanic plateau. The rocks belonging to the Tireo Terrane are unmetamorphosed, although affected by several phases of folding (Lewis et al., 2002).

The Duarte Terrane includes Lower Cretaceous metabasites, metacherts and metapelites deformed and metamorphosed under greenschist and amphibolite facies (Draper and Lewis, 1991; Escuder Viruete et al., 2002). According to Draper and Lewis (1991), Lewis and Jimenez (1991), Lapierre et al. (1999), Giunta et al. (2002) and Escuder Viruete et al. (2007b), the Duarte Terrane is characterized by basalts showing geochemical features typical of an oceanic plateau. According to Escuder Viruete et al. (2007b) two lithostratigraphic units are recognized in the area: the lower one includes low-Ti basalts, high-Ti picrites, high-Mg basalts, Fe-picrites, whereas the upper one is characterized by the occurrence of Fe-Ti basalts. According to geochemistry data (Lapierre et al., 1999; Giunta et al., 2002 and Escuder Viruete et al., 2007b), the Duarte Terrane is generally regarded as a fragment of the Caribbean oceanic plateau. However, whereas Lapierre et al. (1999) have proposed a Late Cretaceous age for the Duarte Terrane, others authors (Draper and Lewis, 1991; Escuder Viruete et al., 2002; 2006; 2007b) favour an Early Cretaceous age. In the Jarabacoa area, this terrane includes two main tectonic units: an amphibolite facies unit thrust onto another unit showing greenschist facies metamorphism. Both these units are deformed into large scale folds with steep axial planes and cut by an east-west trending strike slip fault. The latter structure is responsible for the exposure of the greenschist-facies unit in the southern side of the study area (see Fig. 4).

The Loma Caribe-Tavera Terrane consists of an ophiolite sequence, reported by Escuder Viruete et al. (2007b) as Loma La Monja sequence, composed by serpentinized peridotites (harzburgites and dunites) with subordinate massive and layered gabbros cut by dolerite dykes followed by massive and pillowed basalts. The sedimentary cover is represented by cherts, where a radiolarian assemblage of Oxfor-

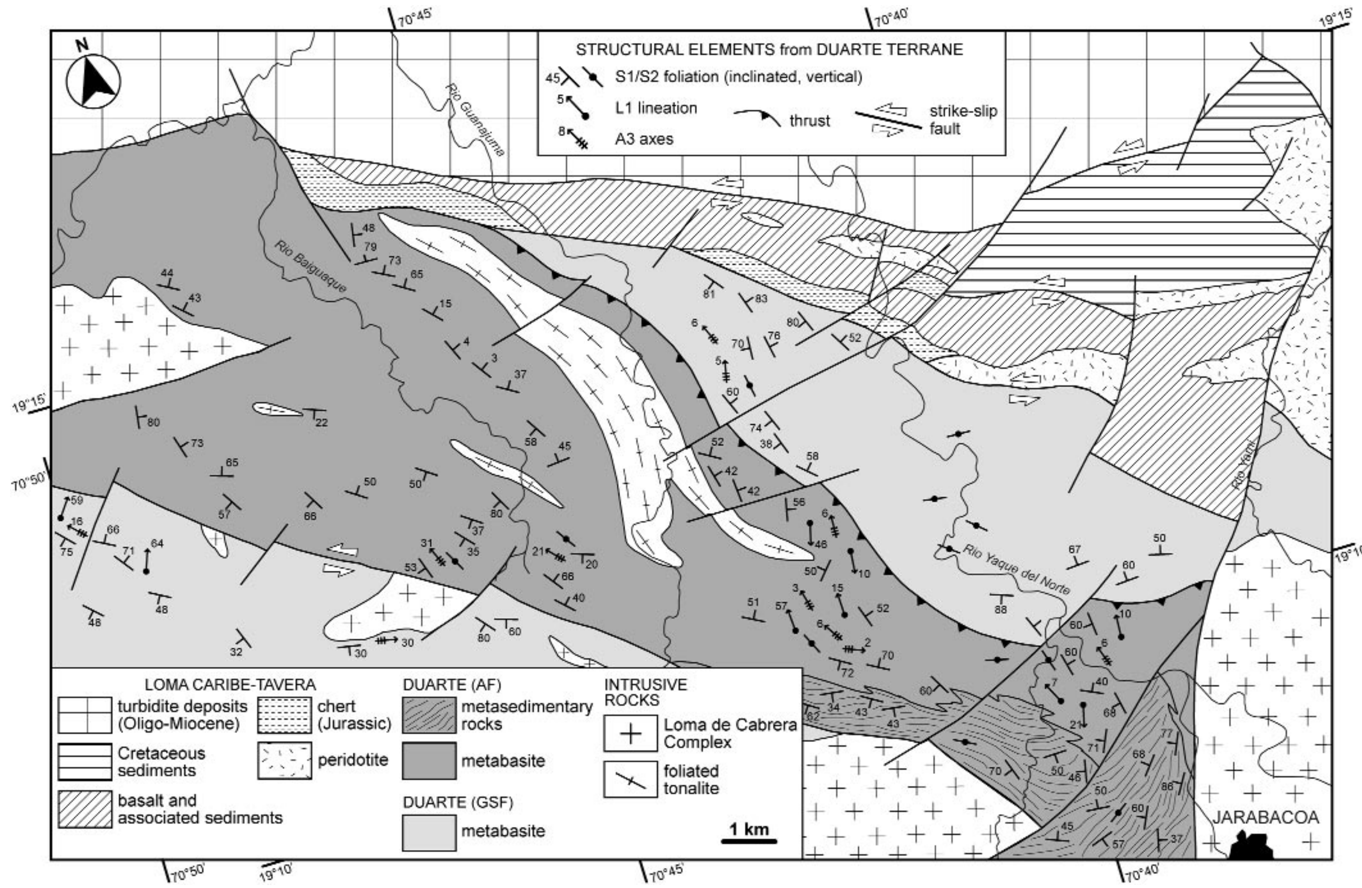

Fig 4 - Geological sketch map of the investigated area (redrawn and modified from Lewis and Jimenez, 1991).

dian to Tithonian age has been found by Montgomery et al. (1994), showing a transition to shales alternanting with rare levels of arenites. This terrane, that is deformed under very low-grade metamorphism, crops out in a narrow NW-SE alignement as a push-up structure along transpressive fault systems, between the Duarte and Tortue-Amina-Maimon-Los Ranchos Terranes. According to Draper and Lewis (1991), Lewis and Jimenez (1991), Lapierre et al. (1999), Giunta et al. (2002) and Escuder Viruete et al. (2007b), the Loma Caribe-Tavera Terrane represents an oceanic crustal section where the oceanic plateau volcanic sequences formed as recognized in the Duarte Terrane.

In the studied area, both the Tireo and Duarte Terranes were intruded before their welding by widespread magmatic rocks belonging to the Loma de Cabrera intrusive complex, consisting of a sequence of ultramafic rocks, gabbro-diorites and horneblende-bearing tonalites cut by swarms of basaltic dykes. Ar-Ar dating of these rocks gives ages spanning from 74.0±1.7 to 88.9±2.6 Ma (Escuder Viruete et al., 2006), corresponding to the second arc stage of Lewis et al. (2002). According to Escuder Viruete et al. (2006), the occurrences of foliated magmatic rocks and the related deformation features indicate that the Loma de Cabrera intrusive was emplaced during the Upper Cretaceous transpression tectonics.

In addition, a small body of foliated magmatic rocks, mainly tonalites, is intruded in the amphibolite facies unit along Rio Guanajuma. These rocks can be correlated with the La Jautia Complex that is intruded in the Duarte Terrane cropping out in the south-eastern Central Cordillera (Bonao and Villa Altagracia area). This complex consists of noritic and gabbro-noritic rocks of Aptian age (Hernaiz Huerta et al., 2000).

THE DUARTE TERRANE IN THE JARABACOA AREA

In the study area, the Duarte Terrane consists of two tectonic units, distinguished by the metamorphic grade. The lower unit is characterized by greenschist facies metamorphism whereas the upper one shows amphibolite facies metamorphic imprint. Both these units are strongly deformed, showing a polyphase history. The proposed tectono-metamorphic history is based on a detailed field survey associated with meso-scale structural analysis performed throughout the whole succession of the units from the Duarte Terrane. Within the Duarte Terrane a complex deformation history consisting of four deformation phases, hereafter referred to as D_1, D_2, D_3 and D_4, has been recognized. The later, brittle tectonics are not described in this paper. During the geological mapping, about 30 oriented samples have been collected and studied in order to outline the main metamorphic mineral assemblages and the microstructural features. Further microscopic analyses have been performed in order to determine the relationships between the recrystallization of metamorphic minerals and their deformation structures. On the selected samples, some mineralogical phases from metamorphic peak mineral assemblages have been analyzed. The mineral chemistry analyses on metamorphic assemblages were performed using a JEOL

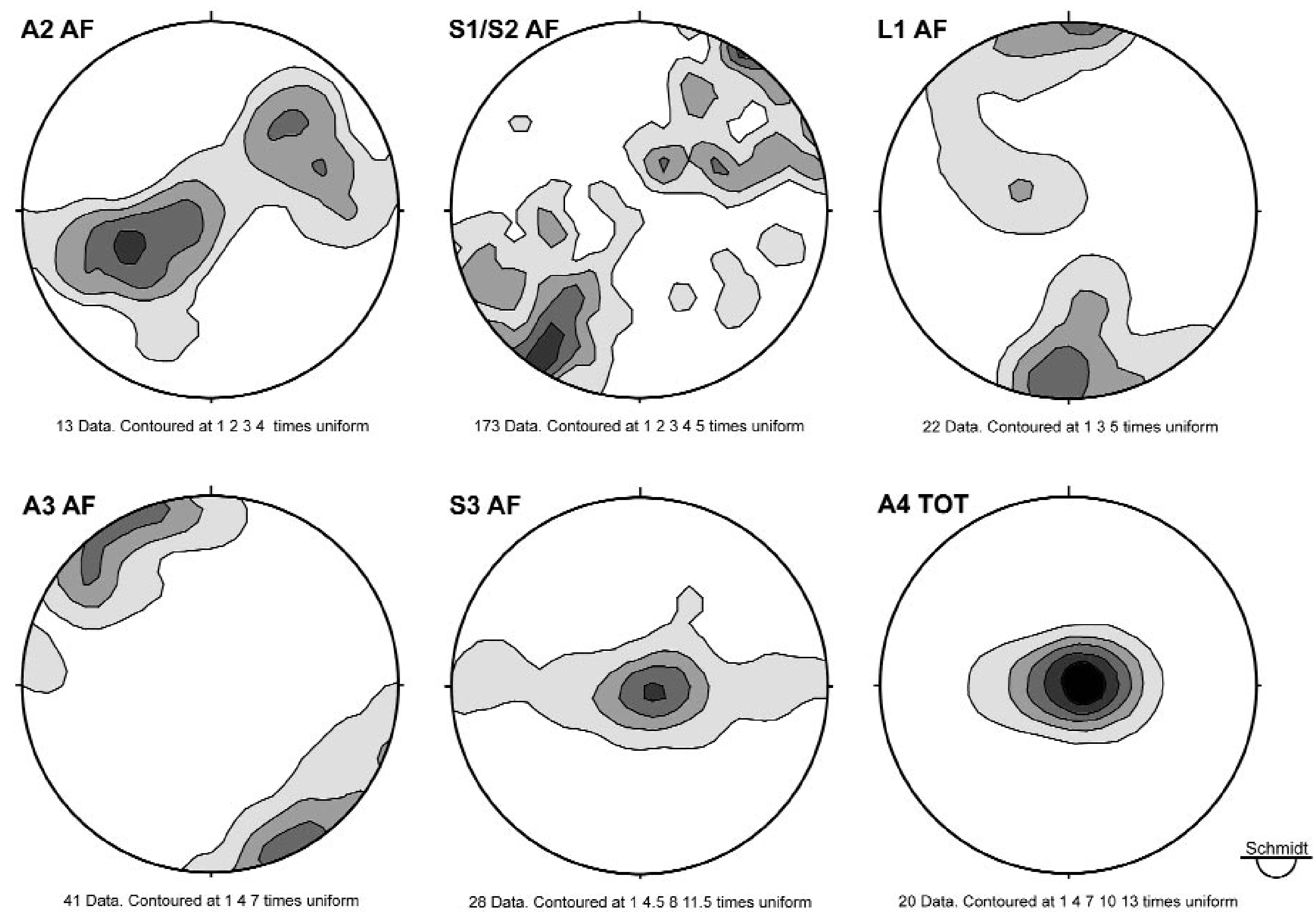

Fig 5 - Stereographic representation of the main structural elements of the amphibolite facies unit from the Duarte Terrane.

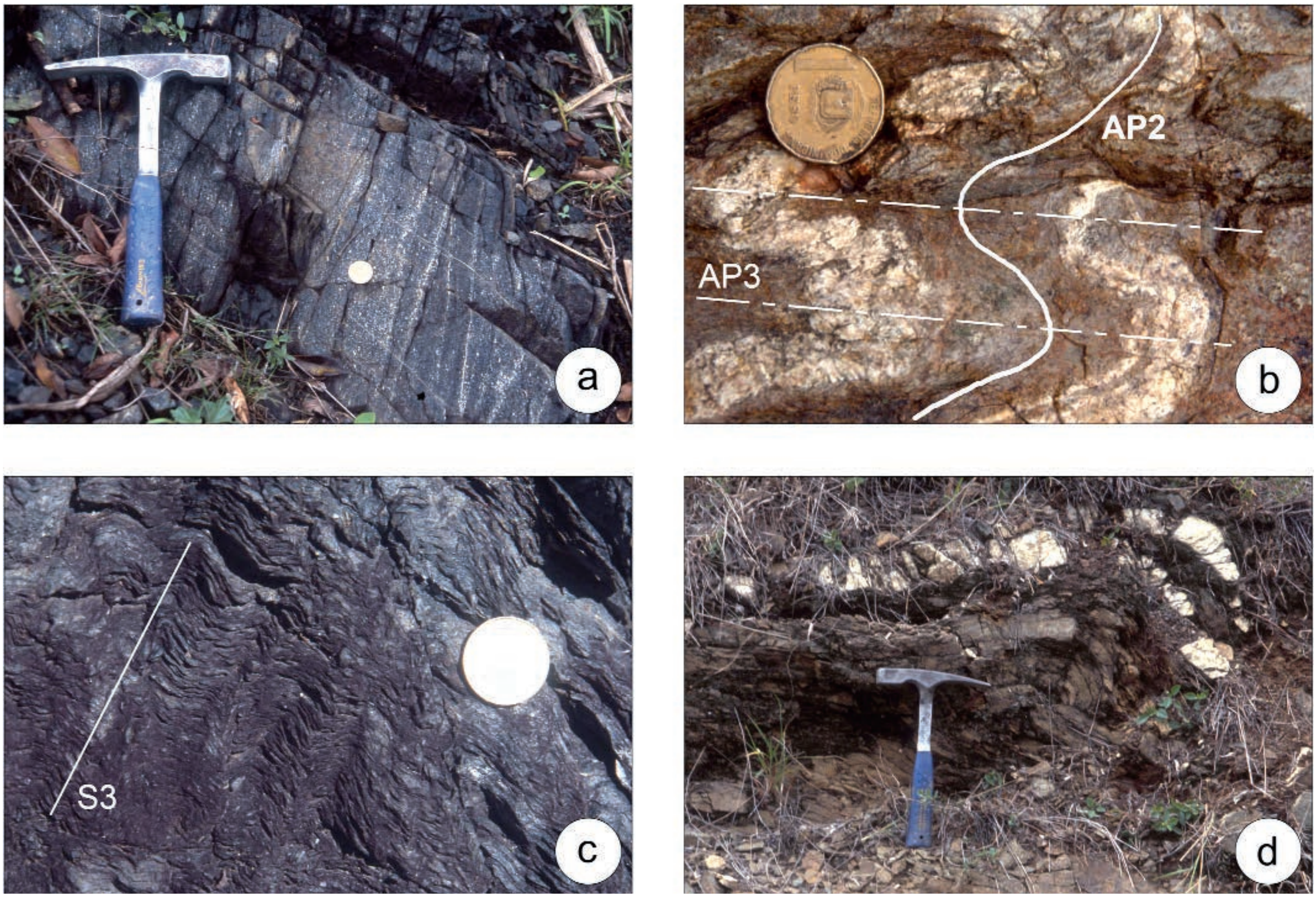

Fig 6 - Mesoscale features of the amphibolite facies rocks from the Duarte Terrane. (a) Main foliation associated to rootless F_2; (b) F_2 deformed by F_3, the two axial planes (AP_2 and AP_3) are indicated; (c) S_3 features; (d) foliated tonalites dykes deformed by F_3.

JXA-8600 electron microprobe analyzer equipped with 4WD-spectrometers (C.N.R.-I.G.G., Firenze - Italy). Running conditions were 15kV accelerating voltage, 10nA beam current on Faraday cage, beam spots between 1 and 10 µm in diameter. The largest spots were used on alkali-rich minerals, to avoid Na-K volatilisation. Natural and synthetic silicates and oxides were used for instrumental calibration.

THE AMPHIBOLITE FACIES UNIT

The amphibolite facies unit comprises two different lithothypes. The first one consists massive to foliated metabasites, sometimes characterized by coarse-grained texture. No relic magmatic structures have been found in the field. As described by Lewis and Jimenez (1991) in the area northwest of Jarabacoa, the metabasites are topped by a second lithotype consisting of metasedimentary rocks. In the log of a drill core from El Yuyo area, Lewis and Jimenez (1991) describe a stratigraphic sequence where the metabasites and the metasedimentary rocks are separated by a 30 m thick sequence of metacherts. The metasedimentary rocks consist of quartz-bearing gneisses and micaschists with levels of massive metaconglomerates including clasts of basic and acid volcanic rocks flattened along the main foliation; pebbles of quartz are also present. The protoliths of these lithologies probably derived from a clastic sequence of shales, sandstones and conglomerates supplied from a source mainly characterized by volcanic rocks. The protoliths of the metavolcanic rocks are rhyodacites (Lewis and Jimenez, 1991), but differently from what described by these authors, the rocks have been identified only as clasts in the metabreccias. Following Lewis et al. (2002), these magmatic rocks can be related to a Lower Cretaceous first stage of arc growth.

The amphibolite facies unit suffered a complex deformation history developed under retrograde P and T conditions. The lithologies are generally strongly recrystallized and the primary features are very difficult to identify. The first deformation phase (D_1) is mainly represented by the foliation (S_1) that can be found in two different occurrences. In the fine-grained amphibolites and gneisses, the S_1 is found as relic foliation largely transposed by deformations developed during the following second deformation phase. By contrast, in the more competent lithologies, as for instance the massive amphibolites, the S_1 is well preserved and only slightly modified. In this setting, the S_1 is coarse-grained and represented by alternating thin (0.5 to 2 mm thick) amphibole- and plagioclase-rich layers. Mineralogical lineations (L_1) consisting of aligned amphibole and plagioclase minerals are well developed on the S_1. The L_1 diagram clearly reveals the N/S trend of these structural elements (Fig. 5). In the amphibolite, also boudinaged and folded quartz veins with a thickness ranging from 5 to 20 cm can be referred to the D_1. In the gneisses, the S_1 developed as alternating quartz- and plagioclase-rich layers characterized by porphyroclasts of quartz. In the associated conglomerates, the S_1 is marked by the shape of the deformed pebbles flattened in the plane of the foliation.

The second deformation phase (D_2) is generally the most common at the mesoscale. It is mainly represented by a continuous and pervasive foliation (S_2), well developed in bands of very fine- and fine-grained amphibolites. These amphibolites are found around large boudins, up to 200 m thick, made of massive amphibolites, where S_2 is generally poorly developed. In the anastomizing bands, S_2, generally parallel to S_1, occurs with different morphology, mainly depending by the lithology. In the very fine-grained amphibolites, S_2 can be defined as fine-grained schistosity characterized by alternating layers of amphiboles and plagioclases. When the grain-size increases, S_2 occurs as spaced foliation characterized by cleavage domains surrounding microlithons where textural remnants of S_1 are preserved in lens-shaped, granoblastic aggregates of plagioclase and amphibole. Therefore, the main tectonic surface detected in the field can be regarded as a S_1/S_2 composite foliation derived from the overprinting of the two deformation phases. Associated to S_2, very rare rootless isoclinal folds (F_2) with thickened hinges have been recognized at both meso and microscale (Fig. 6a). The related axes (A_2) trend at about NE/SW (Fig. 5). The hinges of the F_2 are generally rounded or subrounded, whereas the limbs are strongly boudinaged. The F_2 generally deform the quartz veins or the S_1. When observed on the S_2 plane, the F_2 are strongly non-cylindrical. Their asymmetry suggests a NW vergence.

The third deformation phase (D_3) is represented by open to close folds (F_3) characterized by low-angle axial plane. The F_3 (Fig. 6b) are generally cylindrical without thickening of the hinges nor boudinage of the limbs; their asymmetry points out to a NE vergence. The axes (A_3) have a NW/SE trend (Fig. 5), coherent with the diagram of the S_1/S_2 composite foliation. In the field, the F_3 display an axial plane foliation (S_3) that can be classified as spaced crenulation cleavage (Fig. 6c), generally found at low-angle (Fig. 5). Dykes of foliated tonalites deformed by F_3 have been found in the field (Fig. 6d). In the more competent lithologies the S_3 occurs as a well developed fracture cleavage. Whereas the S_2-S_3 intersection lineation is well developed, the mineralogical lineations are lacking. During the D_3 cataclastic shear zones developed parallel to the S_3.

The fourth deformation phase (D_4) is characterized by open folds (F_4) with vertical axes (Fig. 5) trending about east-west. No axial plane foliation was developed in association with the F_4.

In thin section, the amphibolites are characterized by a strong S_1 (Fig. 7a) defined by the preferred orientation of amphibole and plagioclase. Plagioclase displays an oriented granoblastic structure concentrated in thin layers alternating to bands enriched in nematoblastic amphiboles. The plagio-

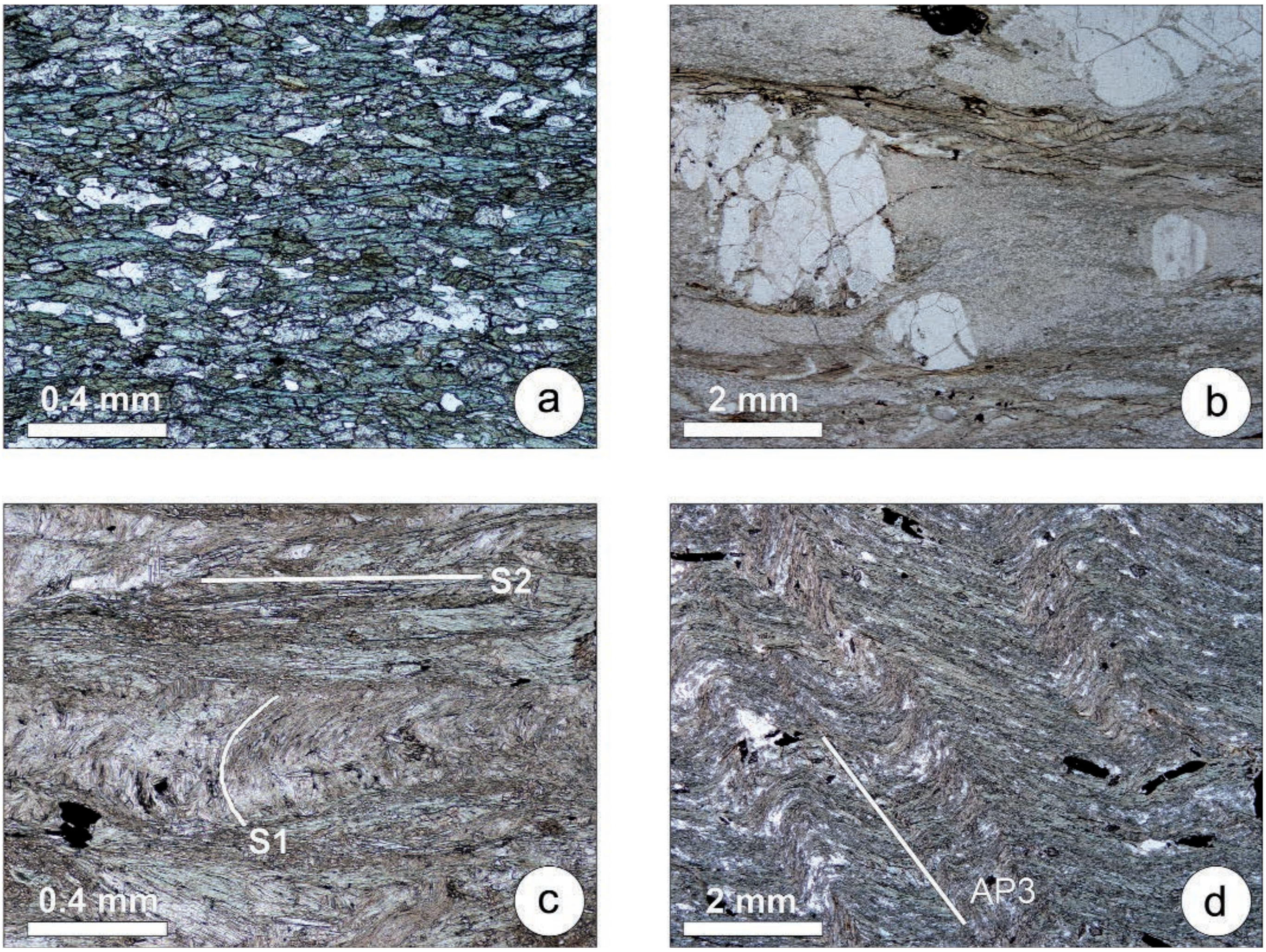

Fig 7 - Photomicrographs of characteristic microstructures and mineral assemblages in the amphibolite facies unit from the Duarte Terrane. Plane-polarized light. (a) Main foliation in the metabasites highlighted by aligned Ca-amphiboles; (b) micro-fabric in the gneisses from the metasedimentary cover: quartz porphyroclasts characterized by asymmetric strain shadows aligned along the main foliation; (c) relationship between S_1 and S_2 in the fine-grained metabasites; (d) main foliation deformed by close micro-F_3 in the fine-grained metabasites. No neoblasts are present along the axial planes of the F_3.

clases show tapered twins whereas the amphiboles display little ondulatory extinction. Quartz and epidote also occur. In the amphibolites, the D_1 assemblage is characterized by the development of plagioclase (andesine) + Ca-amphibole (hornblende/tschermakite) + quartz + epidote. From the D_1 mineral assemblage epidote and Ca-amphibole have been analyzed by electron microprobe (Tables 1 and 2). The epidote structural formulae were calculated assuming 12.5 oxygen and all Fe as Fe^{3+}. The pistacite component $[Fe^{3+}/(Fe^{3+}+Al^{3+})]$ in D_1-related epidote ranges between 0.23 and 0.27. For Ca-amphiboles the structural formulae were calculated assuming 23 oxygen and the classification of Leake et al. (1997) was adopted. Site assignment and ferric iron contents in amphiboles were calculated using the estimation proposed by Schumacher in Leake et al. (1997). The analyzed amphiboles are characterized by a $Mg/(Mg+Fe^{2+})$ ratio ranging from 0.48 to 0.57 and Si contents between 6.21 and 6.60 apfu. These Ca-amphiboles are classifiable as magnesio-hornblende and tschermakite, close to the boundary between the magnesio- and ferro-tschermakite stability fields (Fig. 8). Amphiboles are the most common minerals in metabasaltic rocks, and their compositions can provide useful informations on P-T conditions of metamorphic rocks (e.g., Banno and Sakai, 1989; Otsuki and Banno, 1990; Okamoto and Toriumi, 2004; 2005). The stability field of hornblende suggests a temperature range between 450 and 550°C and a pressure ranging from 0.40 to 0.80 GPa (Okamoto and Toriumi, 2005), coherent with amphibolite facies conditions (Fig. 9). These values agree also with the P and T conditions of 0.49-0.66 GPa and 542-681°C estimated by Escuder Viruete et al. (2002) in the Duarte Terrane cropping out in the Villa Altagracia area.

The gneisses are in turn characterized by prevailing quartz, associated with muscovite and plagioclase, whereas apatite, rutile, magnetite, are accessory phases. Textures are characterized by thin (≤ 1 mm) bands of granoblastic plagioclase + quartz and bands of lepidoblastic micas (Fig. 7b). Quartz porphyroclasts, generally enveloped by lepidoblastic micas, are characterized by σ and δ structures that suggest the presence of non-coaxial strain. The micaschists are in turn characterized by well developed schistosity associated with the synkinematic growth of white mica + quartz + albite. On the whole, gneisses and micaschists are characterized, during the D_1, by the andesina + quartz + white mica + epidote mineral assemblage, probably developed in the same P and T conditions of the amphibolites.

The S_2 can be defined as a zonal crenulation cleavage with smooth and anastomizing cleavage domains (Fig. 7c). The transition between cleavage and microlithons is discrete. According to Escuder Viruete et al. (2002), during the D_2 the actinolite + albite + chlorite + epidote + ilmenite mineral assemblage formed. The coexistence of albite and actinolite (e.g. Banno and Sakai, 1989; Otsuki and Banno, 1990; Okamoto and Toriumi, 2004; 2005) suggests greenschist facies conditions (Fig. 9) with temperature and pressure ranging between 350 and 480°C and 0.20 to 0.60 Gpa, respectively (Okamoto and Toriumi, 2005). In thin section the fine-grained amphibolites and gneisses appear deformed by the associated S_3 is a poorly developed, spaced, crenulation cleavage with smooth shape of cleavage domains showing

Table 1 - Electron microphobe analyses of representative chlorite and epidote

sample / unit	146 / GSF					152 / AF			
phase	Chl1	Chl2	Ep1	Ep2	Ep3	Ep1	Ep2	Ep3	Ep4
Wt%									
SiO2	28.80	28.89	37.60	37.36	37.16	37.96	38.15	38.18	37.49
TiO2	-	-	-	0.09	-	0.09	0.15	0.10	0.14
Al2O3	19.79	19.90	22.95	22.36	22.89	25.03	24.57	24.56	24.40
Cr2O3	-	-	-	0.73	-	-	-	-	0.07
FeO	16.42	17.54	14.47	14.83	14.32	10.64	11.54	11.95	12.90
MnO	0.21	0.33	0.14	0.16	-	0.08	0.19	0.20	0.11
MgO	23.14	23.22	-	-	-	0.06	0.07	0.06	0.00
CaO	0.07	0.05	23.04	22.20	22.91	23.30	23.58	23.07	22.56
Na2O	0.12	0.00	-	-	-	-	-	-	-
K2O	-	-	-	-	-	-	-	-	-
Sum	88.55	89.93	98.20	97.73	97.28	97.16	98.25	98.12	97.67
Cations									
Si	5.713	5.675	3.079	3.081	3.070	3.075	3.074	3.082	3.054
Al vi	2.287	2.325	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum Z	8.000	8.000	3.079	3.081	3.070	3.075	3.074	3.082	3.054
Al iv	2.339	2.282	2.214	2.173	2.229	2.389	2.333	2.336	2.342
Ti	0.000	0.000	0.000	0.006	0.000	0.005	0.009	0.006	0.009
Cr	0.000	0.000	0.000	0.048	0.000	0.000	0.000	0.000	0.005
Fe3+	0.000	0.000	0.990	1.022	0.989	0.721	0.777	0.806	0.878
Fe2+	2.723	2.880	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mn	0.035	0.055	0.010	0.011	0.000	0.005	0.013	0.014	0.008
Mg	6.838	6.795	0.000	0.000	0.000	0.007	0.008	0.007	0.000
Sum Y	11.936	12.011	3.215	3.260	3.218	3.128	3.141	3.169	3.241
Ca	0.015	0.011	2.021	1.961	2.027	2.022	2.035	1.994	1.968
Na	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum X	0.061	0.011	2.021	1.961	2.027	2.022	2.035	1.994	1.968
Sum	19.997	20.022	8.314	8.303	8.315	8.225	8.250	8.245	8.264

GSF: greeenschist facies; AF: amphibole facies; -: below detection limits.

Table 2 - Electron microphobe analyses of representative amphiboles

sample / unit	146 / GSF							152 / AF							
amphibole	Am1	Am2c	Am2r	Am3	Am4	Am5	Am6	Am2r	Am3	Am4	Am5c	Am5r	Am6c	Am6r	Am7
Wt%															
SiO_2	53.75	54.53	55.06	54.98	53.37	54.26	54.67	44.85	42.25	45.01	42.05	42.25	42.68	42.35	42.16
TiO_2	0.91	-	0.06	-	-	-	-	0.39	0.61	0.37	0.68	0.66	0.55	0.44	0.65
Al_2O_3	2.52	2.45	2.00	1.96	2.67	2.09	2.19	10.58	12.85	10.43	13.23	13.33	12.97	12.99	13.15
FeO	10.26	10.73	9.29	9.23	10.10	9.99	9.64	19.18	20.25	20.36	21.49	21.16	21.71	21.78	21.03
MnO	0.07	0.20	0.19	0.22	0.28	0.23	0.22	0.28	0.26	0.23	0.42	0.27	0.24	0.20	0.27
MgO	17.98	18.03	18.51	18.70	17.52	18.20	18.12	10.26	8.30	9.87	8.27	8.49	8.65	8.65	8.11
CaO	12.51	12.43	12.75	12.63	12.38	12.78	12.62	11.46	11.06	11.12	11.05	11.07	11.17	11.10	11.01
Na_2O	0.45	0.37	0.28	0.29	0.51	0.27	0.46	1.58	1.73	1.58	1.68	1.88	1.64	1.72	1.74
K_2O	0.07	0.03	0.06	0.06	0.05	0.05	-	0.15	0.32	0.27	0.34	0.27	0.38	0.30	0.33
Cr_2O_3	-	-	-	0.19	0.18	-	0.39	-	-	-	-	-	-	-	0.06
Sum	98.52	98.77	98.20	98.26	97.06	97.87	98.31	98.73	97.63	99.24	99.21	99.38	99.99	99.53	98.51
Structural formula calculated on the basis of 23 O															
Cations															
Si	7.585	7.637	7.725	7.705	7.615	7.662	7.684	6.584	6.336	6.597	6.211	6.225	6.246	6.224	6.276
Al^{IV}	.415	.363	.275	.295	.385	.338	.316	1.416	1.664	1.403	1.789	1.775	1.754	1.776	1.724
Sum T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	.004	.041	.056	.029	.064	.010	.047	.415	.608	.398	.514	.540	.483	.473	.583
Fe^{3+}	.097	.317	.196	.234	.264	.282	.206	.647	.591	.694	.845	.769	.878	.927	.683
Ti	.097	.000	.006	.000	.000	.000	.000	.043	.069	.041	.076	.073	.061	.049	.073
Cr	.000	.000	.000	.021	.020	.000	.043	.000	.000	.000	.000	.000	.000	.000	.007
Mg	3.782	3.764	3.871	3.906	3.726	3.831	3.796	2.245	1.855	2.156	1.821	1.865	1.887	1.895	1.799
Fe^{2+}	1.021	.879	.871	.810	.925	.877	.907	1.650	1.877	1.711	1.744	1.753	1.691	1.656	1.855
Mn	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Sum C	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mg	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Fe^{2+}	.093	.061	.023	.038	.016	.020	.020	.058	.071	.090	.065	.085	.087	.093	.080
Mn	.008	.024	.023	.026	.034	.028	.026	.035	.033	.029	.053	.034	.030	.025	.034
Ca	1.891	1.865	1.917	1.896	1.893	1.934	1.901	1.803	1.777	1.746	1.749	1.748	1.751	1.748	1.756
Na	.007	.050	.038	.039	.057	.019	.053	.105	.119	.135	.133	.134	.132	.134	.130
Sum B	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.116	.050	.038	.040	.084	.055	.072	.345	.385	.314	.348	.403	.333	.356	.373
K	.013	.005	.011	.011	.009	.009	.000	.028	.061	.050	.064	.051	.071	.056	.063
Sum A	.128	.056	.049	.050	.093	.064	.072	.373	.446	.365	.412	.454	.404	.412	.435
$Mg/(Mg+Fe^{2+})$	.77	.80	.81	.82	.80	.81	.80	.57	.49	.54	.50	.50	.51	.52	.48
name:	Act	Act	Act	Act	Act	Act	Act	Mg-Hbl	Fe-Ts	Mg-Hbl	Fe/Mg-Ts	Fe/Mg-Ts	Mg-Ts	Mg-Ts	Fe-Ts

GSF: greeenschist facies; AF: amphibole facies; -: below detection limits.

gradational transition to microlithons (Fig. 7d). No evidences of microstructures related to the D_4 have been found.

THE GREENSCHIST FACIES UNIT

The greenschist facies unit consists of metabasites with well preserved relics of magmatic structures. Relics of pillow structures are identified as lens-shape bodies. The massive metabasites show transition to basaltic metabreccias, whose protolith were probably volcanoclastic deposits interfingering with tuffs. In the metabasites, relics of clinopyroxene and/or plagioclase have been identified. According to Escuder Viruete et al. (2007b) two lithostratigraphic units are found: the lower one includes low-Ti basalts, high-Ti picrites, High-Mg basalts, Fe-picrites, whereas the upper one is characterized by the occurrence of Fe-Ti basalts.

The greenschist facies unit underwent a polyphase deformation history under retrograde P and T conditions analogue to that recognized in the amphibolite facies rocks.

The first deformation phase (D_1) produced a continuous foliation (S_1) well developed only in the fine-grained lithologies. A mineralogical lineation (L_1), marked by aligned amphibole and plagioclase, is well developed on the S_1. The diagram of the L_1 clearly reveals the NW/SE trend (Fig. 10). In these lithologies the S_1 is associated to intrafoliar isoclinal folds characterized by thickened hinges and boudinaged limbs (F_1). The coarse-grained lithologies, not affected by S_1, occur as large scale boudins set in the foliated rocks.

The second deformation phase (D_2) is mainly represented by tight to isoclinal folds (F_2) with generally rounded or subrounded hinges (Fig. 11a). Their trend is about NE-SW (Fig. 10). These folds are cylindrical and characterized by an axial plane foliation (S_2 foliation), well developed mainly in the fine grained lithologies. The S_2 foliation is generally parallel to S_1 one; so, the main surface detected in the field is a S_1/S_2 composite foliation. Rarely, the interference between S_1 and S_2 has been observed in the hinge zones, where S_2 occurs as a well developed crenulation cleavage. The asymmetry of the F_2 suggests a NE vergence. During the D_2, large cataclastic shear zones characterized by S-C fabric developed parallel to the S_2. The third and fourth deformation phases (D_3 and D_4) show features and trends analogue to those recognized in the amphibolite facies rocks, without significative differences (Figs. 10 and 11b, c and d).

In thin section, the S_1 in the fine-grained metabasites is characterized by the assemblage albite + Ca-amphibole (actinolite) + chlorite + epidote ± quartz ± white mica (Fig. 12a).

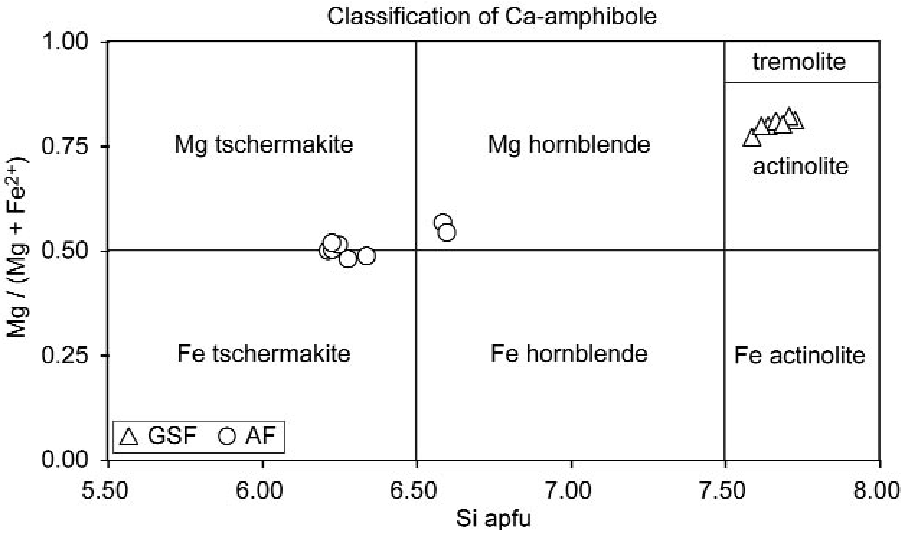

Fig 8 - D_1-related Ca-amphibole composition in the metabasites from the amphibolite facies (AF) and greenschist facies (GSF) units. Plotted in terms of Si apfu vs. $Mg/(Mg+Fe^{2+})$.

Feldspar porphyroclasts with σ and δ structures can be also observed (Fig. 12b). From the D_1 mineral assemblage chlorite, epidote and Ca-amphibole have been analyzed by electron microprobe (Tables 1 and 2). Chlorite structural formulae were calculated assuming 14 oxygen and all Fe as Fe^{2+}. For epidote the structural formulae were calculated on the basis of 12.5 oxygen and assuming all Fe as Fe^{3+}. The pistacite component in the epidote of the greenschist facies unit is higher (0.31-0.32) than in the amphibolite facies unit. For Ca-amphiboles the structural formulae were calculated assuming 23 oxygens, and the classification of Leake et al. (1997) was adopted. Site assignment and ferric iron content in amphiboles were calculated using the estimation proposed by Schumacher, in Leake et al. (1997). The analyzed amphiboles do not show any compositional zoning and they are classifiable as actinolite, with a $Mg/(Mg + Fe^{2+})$ ratio ranging from 0.77 to 0.82 and high amounts in SiO_2 (Fig. 8). The stability field of actinolite (e.g., Banno and Sakai, 1989; Otsuki and Banno, 1990; Okamoto and Toriumi, 2004; 2005) suggests a temperature range between 350 and 480°C and a pressure ranging from 0.20 to 0.60 GPa (Okamoto and Toriumi, 2005), coherent with greenschist facies conditions (Fig.9).

In thin section, the S_2 can be classified as a well developed crenulation cleavage characterized by zonal to continuous cleavage domains that enveloped microlithons where the S_1 is still preserved, even if folded (Fig. 12c). The cleavage domains are general parallel with discrete transition to microlithons. No recrystallization has been found along the S_2. The S_3 consists of well developed disjunctive cleavage (Fig. 12d).

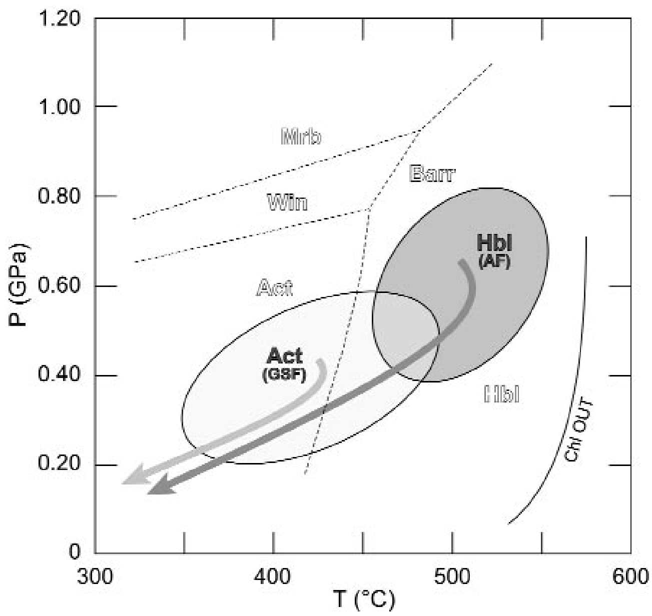

Fig 9 - Schematic P-T paths of the ambphibolite facies (AF) and greenschist facies (GSF) units of the Duarte Terrane, based on the D_1–related Ca-amphibole stability fields (according to Okamoto and Toriumi, 2005). Dashed lines show the amphibole stability fields of Banno and Sakai (1989) and Otsuki and Banno (1990) based on the hematite-bearing schists of the Sanbagawa Belt (Japan), abbreviations: Mrb- Mg-riebeckite; Win- winchite; Act- actinolite; Barr- barroisite; Hbl- hornblende.

THE INTRUSIVE COMPLEXES

According to Lewis and Jimenez (1991), all the lithotypes from the Duarte Terrane are cut by different intrusive complexes, that can subdivided into two groups. The first one consists of foliated tonalites, whereas the second one includes gabbro-diorites and horneblende-bearing tonalites cut by a swarm of basaltic dykes. The first group occurs mainly in the Rio Guanajuma area where the tonalites are intruded in the Duarte Terrane, both foliated and affected by amphibolite facies metamorphism. This suggests that the tonalites were emplaced and subsequently affected by deformation and metamorphism related to the D_1 detected in the Duarte Terrane. This complex can be correlated to that cropping out about 50 km southeast of Jarabacoa near La Jautia area, where Ar/Ar datings of the amphiboles from norites provided an age of 121.4±6 Ma (Hernaiz Huerta et al., 2000).

The second group, most common in the field, comprises tonalites, diorites, granodiorites and monzogranites, interpreted as belonging to the Loma de Cabrera intrusive complex. These rocks occur as undeformed bodies cut by shear zones characterized by a well developed foliation. Escuder-Viruete et al. (2006) found ages spanning from 74.0±1.7 to 88.9±2.6 Ma by Ar/Ar datings. The structural evidence provided by these authors indicates that these granites were emplaced during Upper Cretaceous transpressive tectonics, interpreted as related to the southward oblique subduction of the North America Plate beneath the Caribbean oceanic plateau.

AGE OF THE DEFORMATION PHASES

Several radiometric analyses have been performed in order to assess the age of the rocks from the Duarte Terrane. The most reliable data on the foliated amphibolites are provided by Escuder Viruete et al. (2007b) by Ar/Ar dating on horneblendes recrystallized during the D_1. Two plateau ages of 93.9±1.4 and 95.8±1.9 Ma indicate a Cenomanian age for this phase. Accordingly, a pre-Cenomanian age for the protoliths of the amphibolite facies rocks from Duarte Terrane can be inferred. This age is also confirmed with the Ar/Ar dating of 84±6 Ma of the D_1-related muscovites (Hernaiz Huerta et al., 2000) and 86 ± 4 Ma on amphiboles (Lapierre et al., 1999). In addition, other useful evidences for the age of the deformations in the Duarte Terrane are provided by the Loma de Cabrera intrusive complex that postdates the D_1 and D_2 structures. Ar/Ar dating of the rocks belonging to this complex, points out to ages spanning from 74.0±1.7 to 88.9±2.6 Ma (Escuder Viruete et al., 2007b). Whereas the ages of the D_1 and D_2 can be constrained between the Cenomanian and the Turonian, the ages of the D_3 and D_4, that developed at very low structural levels are most problematic to assess. Probably, the D_3 and D_4 can be related to strike-slip tectonics developed in the Early Oligocene to Early Miocene (Mann et al., 1991).

On the whole, the D_1 and D_2 can be related to the lowermost Upper Cretaceous tectonics (e.g. Mann et al., 1991), that developed before the emplacement of Loma de Cabrera intrusive complex. Differently, the younger D_3 and D_4 can be related to Tertiary transpressive tectonics.

DISCUSSION

In the Jarabacoa area the Duarte Terrane consists of two different units with different metamorphic grade. The upper unit comprises amphibolite facies metabasites topped by metasedimentary rocks, whereas the lower unit consists of greenschist facies metabasites. According to their geochemical features (Draper and Lewis, 1991; Lewis and Jimenez, 1991; Lapierre et al., 1999; Giunta et al., 2002; Escuder Viruete et al., 2007b), the metabasites can be interpreted as remnants of the Caribbean oceanic plateau, whereas the metasedimentary rocks are more problematic. Their lithological features indicate that their protoliths were probably volcanoclastic deposits. The occurrence of rocks classifiable as meta-rhyodacites strongly suggests that the clastic deposits were supplied by magmatic rocks under erosion. In this frame, these metasedimentary deposits can be correlated with those recognized in the Tortue-Amina-Maimon-Los Ranchos Terrane that are referred to the first arc stage growth by Mann et al. (1991) and Lewis et al. (2002). Also the foliated tonalites intruded in the amphibolite facies unit can be referred to the first arc stage, because their lowermost Aptian age.

The deformation history of both units includes four de-

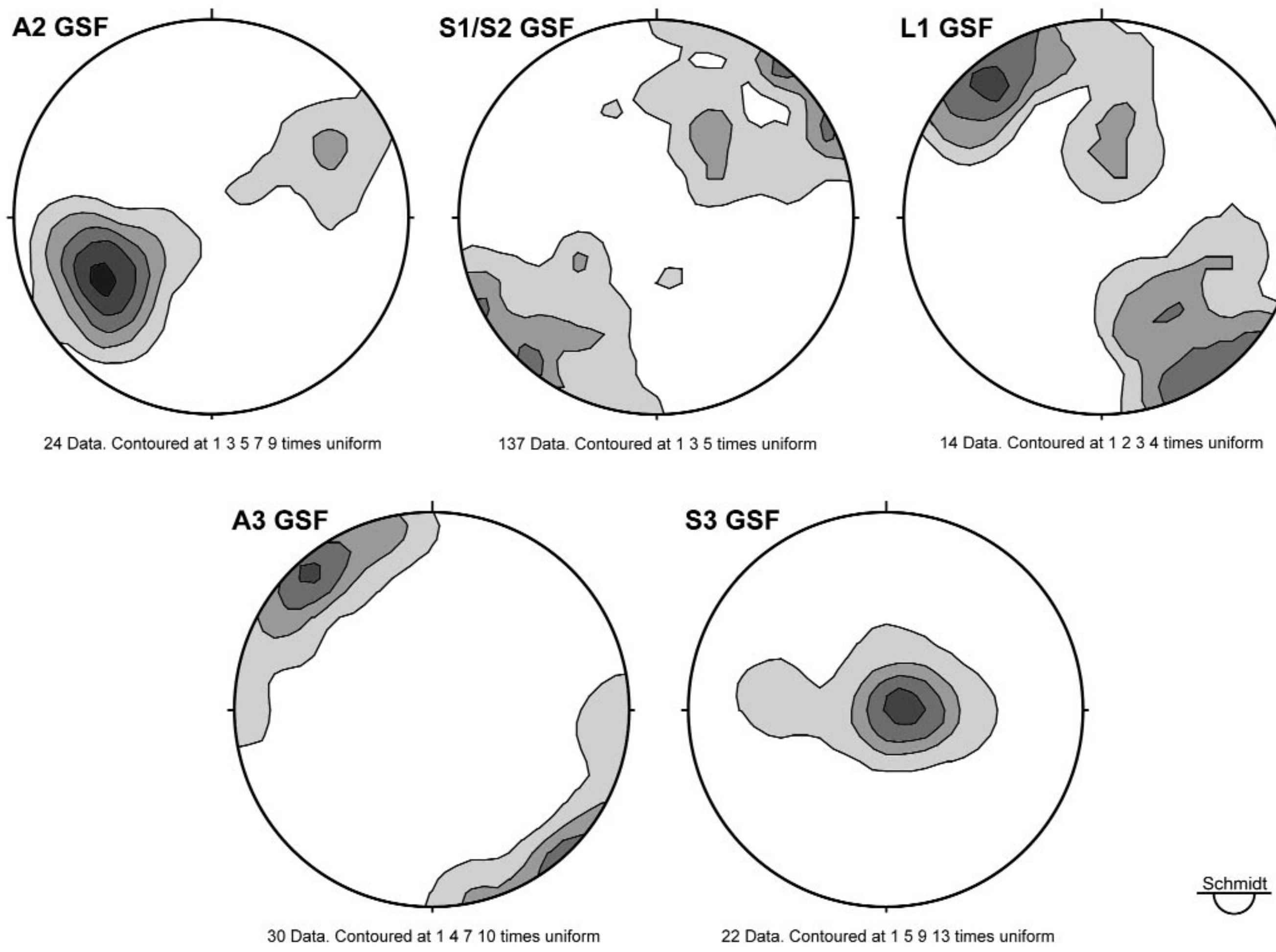

Fig 10 - Stereographic representation of the main structural elements of the greenschist facies unit from the Duarte Terrane.

formation phases, from D_1 to D_4, that can be strictly correlated. In both units the D_1 is characterized by a syn-metamorphic foliation associated to mineral lineations and very rare rootless isoclinal folds. The N/S trending mineral lineations suggest a displacement of the Duarte Terrane perpendicular to the plate boundary. In both units, metamorphism developed under a high geothermal gradient, probably ranging from 25 to 30°C/km. This thermal gradient is typical of the continental collision stage but can be also referred to syn-convergence deformation in an arc setting, as proposed for the northern margin of the Caribbean Plate by Lewis et al. (2002). In both units, the D_2 is characterized by a well developed foliation and isoclinal folds acquired under retrograde metamorphic conditions. Therefore, the D_2 can be regarded as responsible for the exhumation of the units from the Duarte Terrane. The tectonic relationship of these units, i.e. the more metamorphic unit over the less metamorphic one, is consistent with exhumation driven by thrusting and leading to imbrication of units with different metamorphic grade. The shear zone located at the boundary between the two units corresponds to a sharp change in metamorphic grade. This occurrence indicates a tectonic scenario very different to that described by Escuder Viruete et al. (2002) in the Villa Altagracia area, where a continuous transition from low- to medium- and high-grade metamorphic rocks has been recognized. In addition, the attitude of the shear zones, parallel to the main foliation in both units strongly suggests that it developed during or before the D_2. The D_1 and D_2 deformation has been acquired in the Cenomanian-Turonian time span, i.e. after the proposed reversal of the subduction and during the southward oblique subduction of the oceanic lithosphere of the North America Plate beneath the Caribbean oceanic plateau (Lewis et al., 2002). In this frame, the D_1 and D_2 recognized in the Duarte Terrane can be related to intra-arc deformation acquired during the inception of subduction of the North America continental crust beneath the Caribbean oceanic plateau, corresponding either to the second arc stage of Lewis et al. (2002) and Escuder Viruete et al. (2002) or to the second eo-Caribbean stage of Giunta et al. (2003; 2006). The presence of foliated tonalities intruded in the amphibolite facies Duarte Terrane seems to demonstrate that the first volcanic arc was built inside the oceanic plateau. In this scenario, no evidence of deformations connected with the pre-Aptian collision of the first stage arc system (i.e. Tortue-Amina-Maimon-Los Ranchos terranes) against the oceanic plateau has been detected in the Duarte Terrane. Therefore, the Duarte Terrane diplays only record of deformations connected with the southward oblique subduction of the oceanic lithosphere of the North America Plate beneath the Caribbean oceanic plateau, whereas evidences for the tectonics associated to northward dipping subduction is lacking.

The differences in metamorphism between Duarte and Loma Caribe-Tavera Terranes indicate that the no metamorphosed ophiolite sequence from the latter terrane cannot directly be interpreted as the basement of the metabasites from the Duarte Terrane, where the rocks are affected by greenschist and amphibolite facies metamorphism.

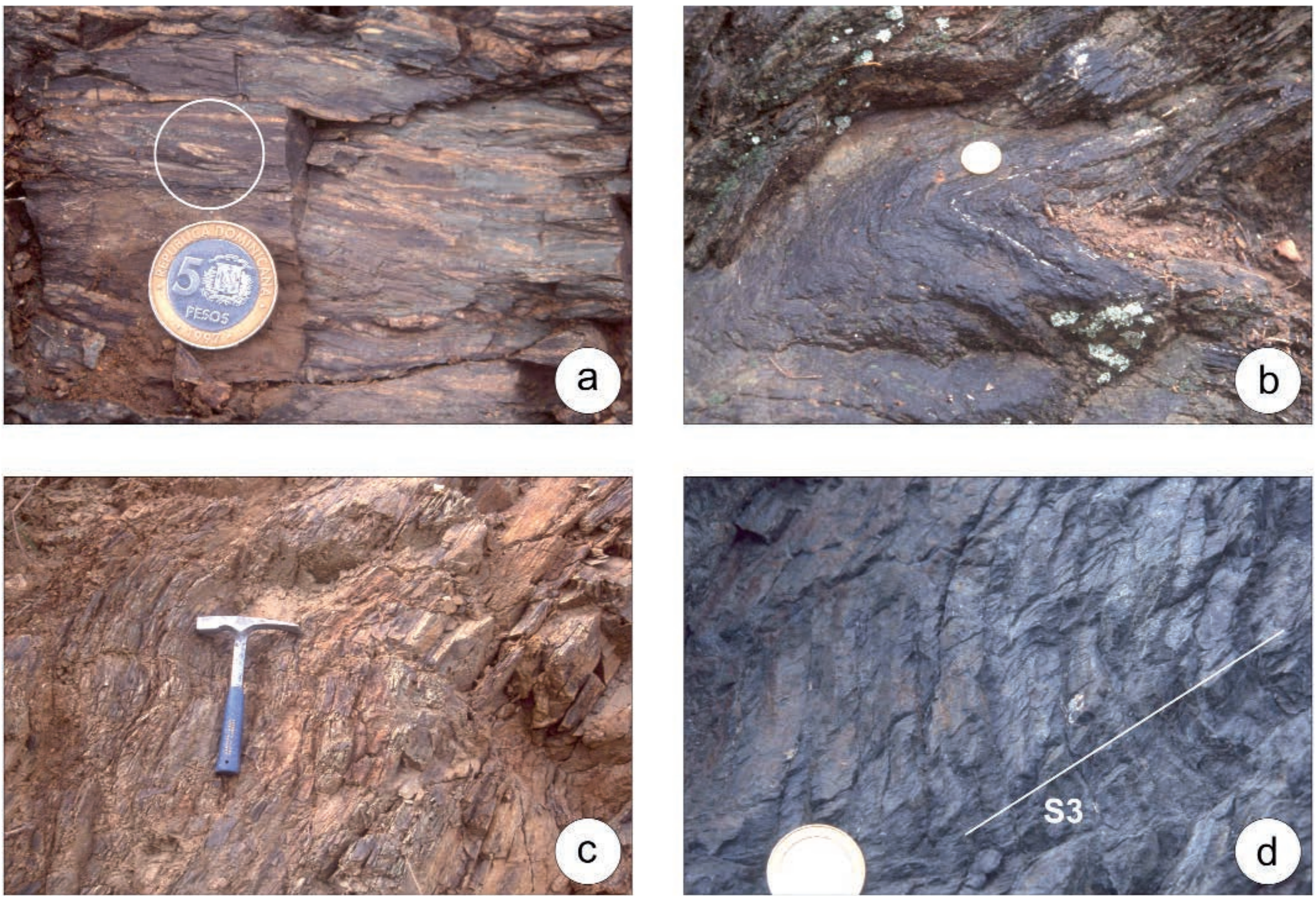

Fig. 11 - Mesoscale features of the greenschis facies rocks from Duarte Terrane. (a) Main foliation associated to F_2 (circle); (b) F_3 features; (c) F_3 feautures in massive metabasalts; (d) F_3 features in fine-grained basalts, the S_3 is indicated.

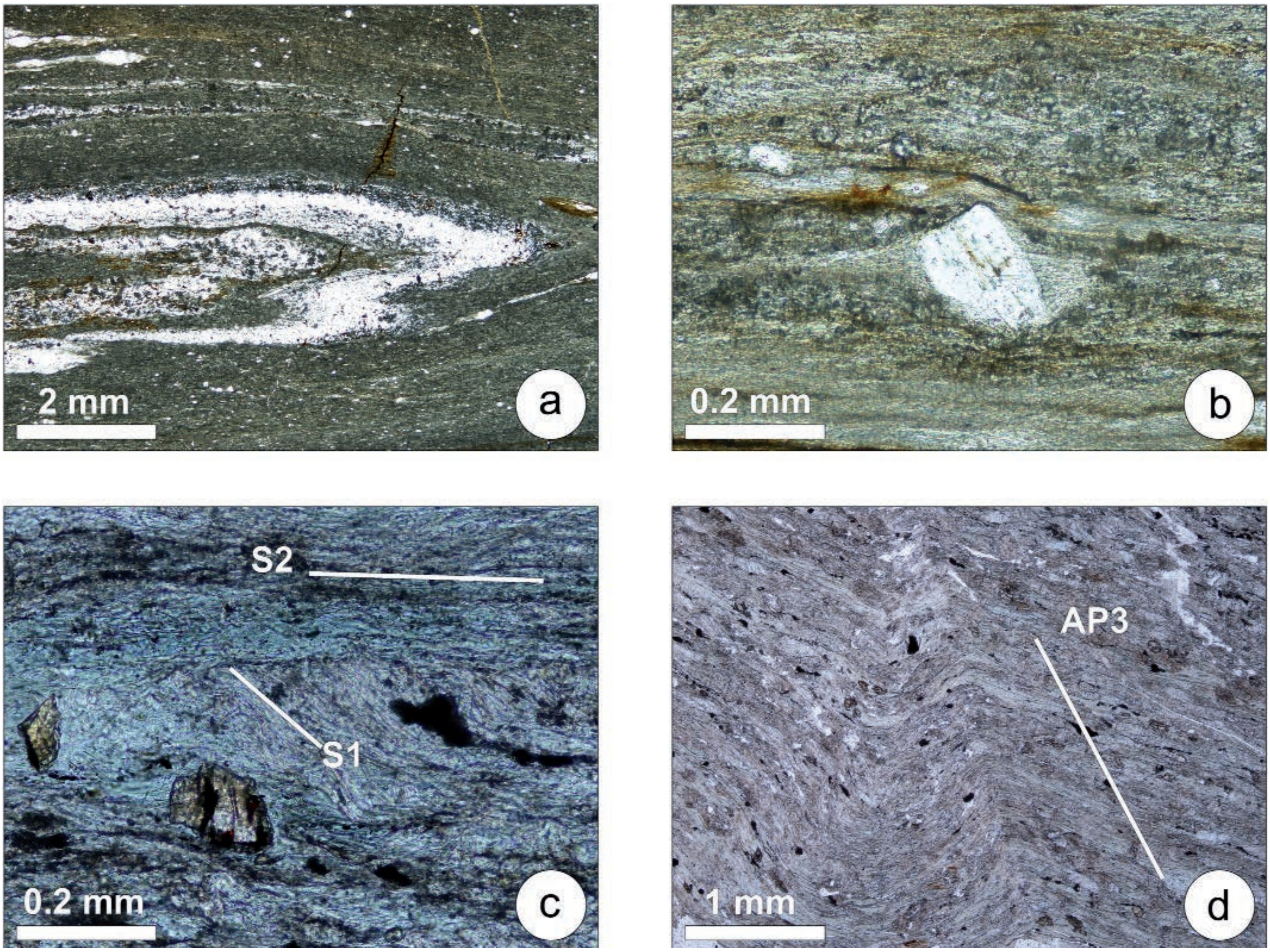

Fig 12 - Photomicrographs of characteristic microstructures and mineral assemblages in the greenschist facies unit from the Duarte Terrane. Plane-polarized light. (a) Hinge zone of an isoclinal F_2 in the metabasites; (b) Feldspar porphyroclast showing asymmetric strain shadows aligned along the main foliation; (c) relationship between S_1 and S_2 in the metabasites, (d) main foliation deformed by micro-F_3 in the metabasites. No neoblasts are present along the axial planes.

The D_3 and D_4 are of Tertiary age, probably Early Oligocene to Early Miocene. The D_3 is characterized by open to closed folds with a NW-SE trend. These folds can be regarded as belonging to an "en echelon" system connected with the transpressive tectonics leading to the development of the terranes that are bounded by E-W trending strike-slip fault bands. The same conclusions can be drawn for the following D_4, in turn characterized by E-W trending open folds with subvertical axes, that can be correlated to subvertical strike-slip faults found inside and at the boundaries of the Central Cordillera terranes. According to Giunta et al. (2006), the transpressive tectonic regime that characterized the whole northern margin of the Caribbean Plate since the latest Cretaceous, was responsible for the present day tectonic setting.

Finally, it is important to outline that whereas the D_1 and D_2 indicate shortening perpendicular to the plate boundary, the subsequent emplacement of the Loma de Cabrera intrusive complex and the following D_3 and D_4, occurred in a transpressive setting. The change of the deformation from pure to strike-slip compressive tectonics is typical of oblique convergence, as recognized for instance also in the southern margin of the Caribbean Plate (e.g., Ellero et al., 2007). Physical modelling (e.g., McCaffrey, 1992; Chemenda et al., 2000) has demonstrated that oblique subduction is characterized by strain partitioning that consists in the accommodation of the oblique plate convergence by both normal- and parallel-trench displacement in the upper plate leading to the development of strike-slip faults in the fore- and back-arc zones. However, the strain partitioning requires a high value of interplate friction. When the value of this parameter is low, the arc setting is characterized by shortening or extension, both perpendicular to the plate boundary. Therefore, the alternation of different types of deformations in the arc setting during oblique subduction can be regarded as the result of changes in the interplate friction values. In this scenario, the differences in the structure of the subducting plate through time in the same geodynamic setting, i.e. an oblique subduction zone, can be regarded as the most probable mechanism to explain the changes in the interplate friction values.

CONCLUSIONS

The collected data indicate that the Duarte Terrane in the Jarabacoa area consists of two units, with different metamorphic facies: the lower one is characterized by greenschist facies whereas the upper one by amphibolite facies. The succession of these units is characterized by metabasic rocks, that in the upper unit are topped by metasedimentary rocks. The metabasites, probably of Early Cretaceous age, are representative of the Caribbean oceanic plateau volcanic rocks, whereas the metavolcanoclastic rocks are related to the first stage arc growth, according to the reconstruction proposed by Mann et al. (1991) and Lewis et al. (2002). To the first stage of arc growth can be referred also the foliated tonalities recognized as bodies intruded into the amphibolite facies unit of the Duarte Terrane. The age of these magmatic rocks is earliest Aptian.

The deformation history recognized in both units consists of four phases, from D_1 to D_4. The D_1 is characterized by a well developed foliation and mineral lineation developed under metamorphism ranging from amphibolite to greenschist facies. The D_2 is, in turn, responsible for the exhumation of both the units, probably during a compressive event. The D_1 and D_2 developed in the Cenomanian-Turonian, just before the magmatism related to the second stage arc of growth, that can be referred to a Campanian-Maastritchian time span. The following Upper Oligocene to Upper Miocene transpressive tectonics is responsible for the development of the terranes recognized in the Hispaniola Island. In the Duarte Terrane, the D_3 and D_4, that acted at very shallow structural levels, can be referred to transpressive tectonics. On the whole, the deformation history of the Duarte Terrane occurred in the arc setting during oblique subduction leading to alternation through time of compressive and transpressive tectonics, responsible for the Hispaniola present-day structural setting.

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